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Reviewing the effect of CO_2 and the sun on global climate

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ABSTRACT

This paper discusses the effect of the greenhouse phenomenon and CO_2 on global climate and suggests that numerical models that lack adequate knowledge of fundamental related factors cannot be used to extract “sound” conclusions. A very basic demonstration of this is done through a simple comparison between estimates of the forecast for global temperature increase obtained by various independent studies. Observing the global temperature and the CO_2 atmospheric concentration though the geological aeons implies no obvious correlation. Physical observation on other planets like Mars and Venus, needing no numerical modeling, demonstrates the effect of the atmospheric-CO_2 partial pressure on the temperature of the atmosphere. Moreover the CO_2 role as a factor of danger or a benefactor for life is also addressed. On the other hand the role of the sun in the presently observed global warming has been greatly underestimated. Scientific evidence shows that the orbit of the earth and the Milankovitch cycles greatly affect the climate. A discussion follows pointing out the prime role that the sun should have on the earth's climate with regard to solar cycles' activity and irradiance, cosmic rays and cloud formation. The conclusion drawn here is that a natural signal of solar forcing has been mistakenly overlooked for an anthropogenic change, maybe owing to their quite similar effects on climate. For the moment science does not really have a complete and total understanding of the factors affecting the earth's complex climate system and therefore no sound conclusions can be drawn.

Contents

1. Introduction

The climate of the earth is of a major importance for mankind because mankind's prosperity is directly linked to it. Observing the climate through the aeons it can easily be seen that when the

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climate was "warm" (with even higher temperatures than today's "warm" period) mankind expanded in numbers and power. Some of such periods are well-known historical periods like the Minoan, the Roman, the Mediaeval as well as present time [1]. This is due, in part, to the increase in crop production. Therefore the very high interest of the recent years about the factors that affect the climate is more than justified especially because of the observation that the global temperature had been increasing during nearly the whole 20th century.

The initial (and obvious) observation that CO_2 also increased during the same time-period, from about 290 ppm (per volume) at the beginning of the 20th century to its present (2009) value of about 385 ppm [2], made CO_2 the prime suspect to be blamed for the temperature increase. The Intergovernmental Panel on Climate Change (IPCC) of the United Nations led the way in blaming CO_2 for the observed warming and consequently a large number of Governments signed treaties for diminishing the burning of fuels in order to minimise the CO_2 increase in the atmosphere and save the planet from warming.

There are though other factors – besides the greenhouse gases – that affect the global temperature, like changes in solar activity, cloud cover, ocean circulation and so forth.

For the past 4.5 billion years the earth has been traveling through galactic space. The global climate has changed drastically through time with variations between ice-free and glaciated climates. One could suggest that these variations would primarily be caused by astronomical factors like the galactic environment and the activity of the sun, and secondarily by internal factors on earth like the changing of the environment. Actually, the geological record of the past 510 million years shows four alternations between "hothouse" and "icehouse" conditions during the Phanerozoic aeon, which can be attributed to four encounters with the spiral arms of the Milky Way with every encounter causing an icehouse episode [3]. On a smaller scale we would observe that the temperature always fluctuates, showing warm and cold episodes without the need of mankind intervention. As is well demonstrated with the analysis of the Vostok ice cores [1] the temperature may fluctuate with differences of as much as 12 K in a time-span of about 100–125 thousand years. This is normally due to the angle and distance of the earth to the sun.

The sun as the central energy source of our planetary system immensely affects the earth's global life conditions. The sun emits electromagnetic radiation in various forms like infrared radiation (that we feel as heat), visible light, ultraviolet rays, microwaves, X-rays, gamma rays and so forth. All forms of electromagnetic radiation travel through space at the speed of light. At this rate, a photon emitted by the sun takes 8 min to reach the earth, which is at an average distance of about 149,600,000 km. The amount of electromagnetic radiation from the sun that reaches the top of the earth's atmosphere, known as the solar constant, is about 1365 W m^{-2}. The atmosphere blocks some of the visible and infrared radiation, almost all the ultraviolet rays, and all the X-rays and gamma rays. The sun also emits particle radiation, consisting mostly of protons and electrons comprising the solar wind. The earth is protected against the solar wind by its magnetic field that prevents the particle radiation from reaching the surface. The sun shows great activity on its surface and bounding area and a lot of phenomena can be observed. Flares and coronal mass ejections are violent eruptions involving a tremendous amount of matter sent into space (see Fig. 1).

But how much do we know about the sun activity and how it affects the earth's climate? The truth is that there is still low scientific understanding of the solar irradiance (one of many features of the sun that may affect the global climate) [4] and this is due to the lack of experimental data. Some more insight on this can be found in [5], where the factors that affect the sun radiation reaching the earth on long time scales are presented extensively. Also in [6] some of the evidence for a solar influence on the lower atmosphere is reviewed and some of the mechanisms whereby the sun may produce more significant impacts than might be expected by the mere consideration of variations in solar irradiance are discussed.

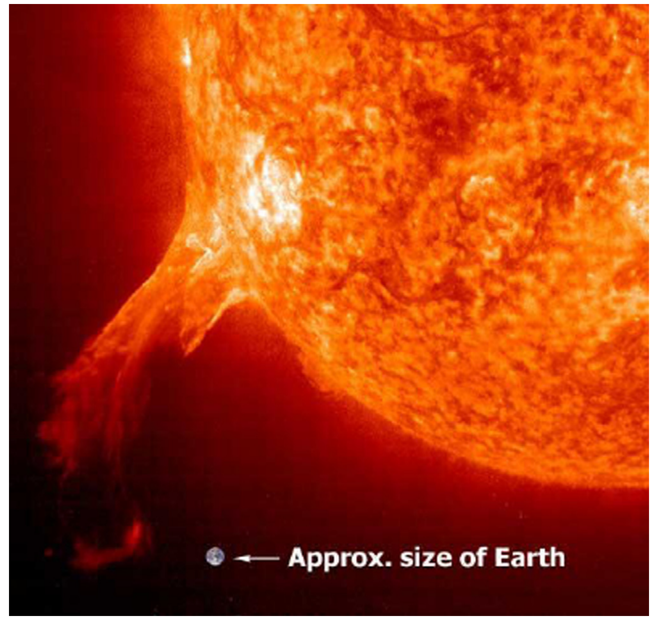

Fig. 1. Size of earth compared to the sun and a solar flare (credit: jpl.nasa.gov).

The rest of the paper is organized as follows. In Section 2 the effect of the greenhouse phenomenon and CO_2 on global climate is discussed on the basis of 'dubious' appropriateness and numerical models that lack adequate knowledge of fundamental related factors. A demonstration of this is a comparison between estimates of the forecast for global temperature increase, which follows comparisons of global temperature and CO_2 atmospheric concentrations though the geological aeons in order to estimate any relation. Also mentioned in Section 2 is the effect of the atmospheric CO_2 partial pressure on surface air temperature indicated through physical observations on other planets. Moreover the CO_2 role as a factor of danger or a benefactor for life is also addressed. In Section 3 it is demonstrated how there is evidence that the orbit of the earth in relation to the Milankovitch cycles may greatly affect the climate. The whole of Section 4 is concerned with a discussion pointing to the prime role that the sun should have on the earth's climate with regard to solar cycles activity and irradiance, cosmic rays and cloud formation. We conclude with Section 5.

2. CO_2 and the greenhouse effect

2.1. Modeling the climate system

The sun powers the climate of the earth, radiating energy at very short wavelengths [7]. Roughly one-third of the solar energy that reaches the top of the earth's atmosphere is reflected directly back to space. The remaining two-thirds are absorbed by the surface and, to a lesser extent, by the atmosphere. The earth balances the absorbed incoming energy, by radiating on average the same amount of energy back to space at much longer wavelengths primarily in the infrared part of the spectrum. Much of this emitted thermal radiation is absorbed by the atmosphere and clouds, and is reradiated back to earth warming the surface of

the planet and causing the so called "greenhouse effect." Without this natural greenhouse effect life, as we know it, would not be possible because the average temperature at the earth's surface would be below the freezing point of water.

However, as it is by and large accepted, most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations (see, for example, [4]). It is argued that it is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica). Atmospheric concentrations of CO_2 (379 ppm) and CH_4 (1774 ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are mainly due to fossil fuel use and land-use change that provides another significant but smaller contribution. It is very likely that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. However the CH_4 growth rates have declined since the early 1990s. CO_2 is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004.

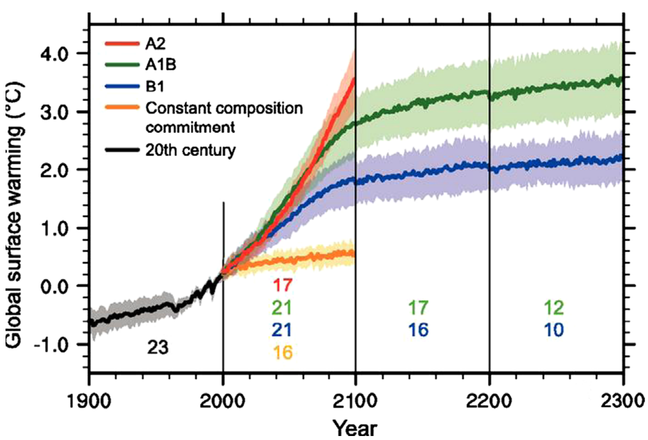

Fig. 2. Multi-model means of surface warming (relative to 1980–1999) for various scenarios, shown as continuations of the 20th-century simulation (black line). Lines show the multi-model means and shading denotes the ± 1 standard deviation range of individual model annual means. Colored numbers indicate periods and scenarios. Refer to [11] for a detailed explanation.

Water vapor is the most important gaseous source of infrared opacity in the atmosphere, accounting for about 60% of the natural greenhouse effect for clear skies [8] with CO_2 being the second-most important one. The amount of warming depends not only on the added amount of GHG, especially CO_2, but also on the various feedback mechanisms. This happens because, as the atmosphere warms up due to rising levels of GHG, its concentration of water vapor increases, further intensifying the greenhouse effect. This in turn causes more warming, which consequently causes an additional increase in water vapor in a self-reinforcing cycle. This water vapor feedback may be strong enough to approximately double the increase of the greenhouse effect due to the added CO_2 alone.

IPCC reports that climate has changed in some defined statistical sense and assumes that the reason for that is anthropogenic forcing. As it states, traditional approaches with controlled experimentation with the earth's climate system is not possible. Therefore, in order to establish the most likely causes for the detected change with some defined level of confidence, computer model simulations are used. The results of the computer simulations show that anthropogenic CO_2 emissions to the atmosphere are the main reason for the observed warming and that doubling the amount of CO_2 in the atmosphere will increase the temperature by about 1.5–4.5 °C [9]. A similar result is mentioned in [10], where the equilibrium global mean warming for a doubling of atmospheric CO_2 is likely to lie in the range of 2–4.5 °C, with a most likely value of about 3 °C (see Fig. 2).

Additionally, according to [12] during the past 50 years, the sum of solar and volcanic forcing would likely have produced cooling, not warming, and hence the observed patterns of warming and their changes are simulated only by models that include anthropogenic forcing and not external forcing. Therefore it is further concluded that, with very high confidence, the global temperature increase is due to the net effect of human activities since 1750.

The conclusion above is the result of computer model simulations as controlled experimentation with the earth's climate system is not yet possible. In [4, Fig. 2.4] a table describing the radiative forcing components and the assessed level of scientific understanding of each component is given (see Fig. 3). It is very

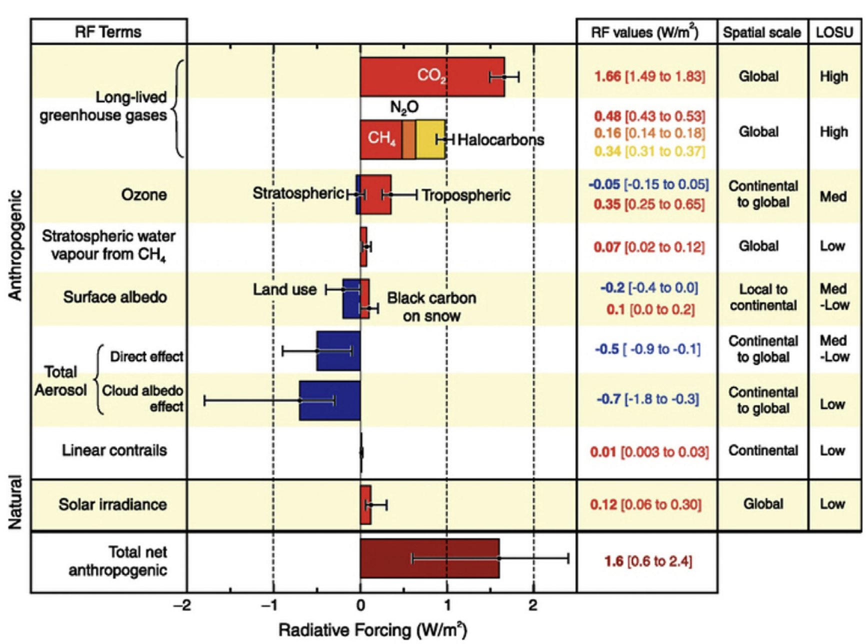

Fig. 3. Global average radiative forcing (RF) in 2005 with respect to 1750 and the assessed level of scientific understanding (LOSU) as given in [4].

clear that our understanding of the effect of solar irradiance is low and the same is true for a variety of other components with medium to low level of understanding. Very important natural factors, like the effect of water vapor and clouds, are not even mentioned in this table. Therefore a serious question arises: how can the models simulate the global temperature if the scientific basis is not well understood? Because of this the Committee on the Science of Climate Change-National Research Council [13, p. 15] states that “Climate models calculate outcomes after taking into account the great number of climate variables and the complex interactions inherent in the climate system. Their purpose is the creation of a synthetic reality. (…) They also are the appropriate high-end tool for forecasting hypothetical climates in the years and centuries ahead. However, climate models are imperfect. Their simulation skill is limited by uncertainties in their formulation, the limited size of their calculations, and the difficulty of interpreting their answers that exhibit almost as much complexity as in nature.”

If the governing models for the climate system are derived without any sound theoretical background given that we do not have a good understanding of all related physical factors, computer simulations become merely a form of data curve fitting. Moreover, needless to say that, for a simulation model to be of a significant value, it must first be validated against the results of real experimental measurements for sufficient time intervals. Also it is common knowledge that during simulations the slightest change in the value of a parameter (physical or mathematical) may affect greatly the final outcome. Hence, a “correct” choice of parameter values may lead to precise results with increasing time, whereas at the same time a “wrong” choice may yield large errors. Concluding, one can clearly understand that in a system of many parameters (like the climate system) the precision of the final outcome is even more dependent and sensitive to parameter variation. Sorokhtin and collaborators [14] stress that a sound theory, using laws of Physics, for the greenhouse effect was lacking and all predictions were based on intuitive models using numerous poorly defined parameters. Their examination showed that at least 30 such parameters were contained in the models.

After a decade or more from the use of climate models it is worth checking how well these can predict the global temperature. Spencer [15] reprints the predictions of 44 Climate models and the actual University of Alabama in Huntsville (UAH) and Remote Sensing Systems (RSS) satellite observations for global lower tropospheric temperature variations. The black line in the plot (Fig. 4) shows the 44-model average, and it approximately represents what the IPCC uses for its official best estimate of projected warming. Obviously, there is a substantial disconnect between the models and observations for this statistic and shows that the models do not depict reality well.

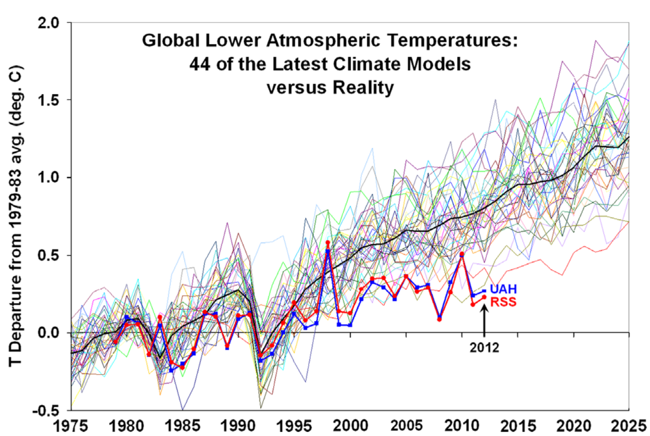

Fig. 4. Spencer's [15] comparison of 44 climate models versus the UAH and RSS satellite observations for global lower tropospheric temperature variations (1979–2012 from the satellites and 1975–2025 for the models).

2.2. Past records

Studying past records is an undeniable tool to test the assumption that CO_2 is the main driving factor for the earth climate. The first time period under consideration refers to the last millennium. As Veizer [16] mentions, Greenland is a representative case for the climate record of the northern hemisphere. The calculations based on oxygen isotope values in ice layers suggest that the temperatures in the 11th century were similar to those of today (Fig. 5). This warm interval was followed by a temperature decline until the 14th century, then by generally cold temperatures that lasted until the 19th century, and finally by a warming in the 20th century. Note that the coeval “ice bubble CO_2” pattern in Greenland and Antarctic ice caps was essentially flat (IPCC-[17]), despite these large climatic oscillations. CO_2 begins to rise only at the termination of the “Little Ice Age”, toward the end of the 19th century.

Examining the palaeoclimate one can compare the temperature data and the CO_2 variation during greater time spans in order to obtain a deeper insight on how the CO_2-concentration change affects the temperature.

In Fig. 6 the temperature difference in Antarctica (as measured in ice cores by Jouzel et al. [36] is compared to various CO_2 concentrations: Petit et al. [20] for the past 420,000 years from the Vostok ice cores and Monnin et al. [21] for the High resolution records of atmospheric CO_2 concentration during the Holocene as obtained from the Dome Concordia and Dronning Maud Land ice

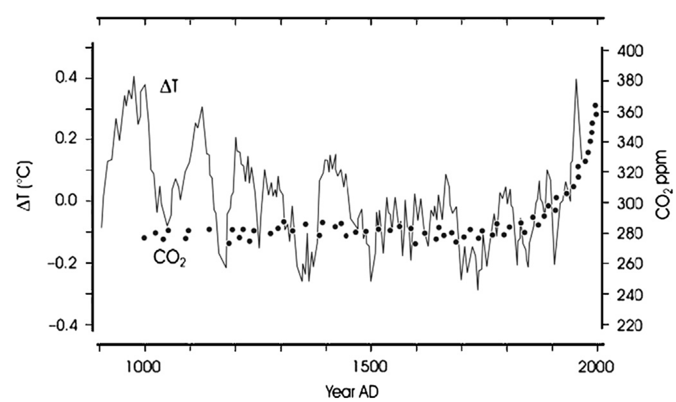

Fig. 5. The temperature change (ΔT) and CO_2 records of the last millennium from a Greenland ice core (GISP2). Temperature was calculated from the 50-year smoothed record as $T = 0.6906 \cdot \delta 18O - 13.68$ (adapted from [18]).

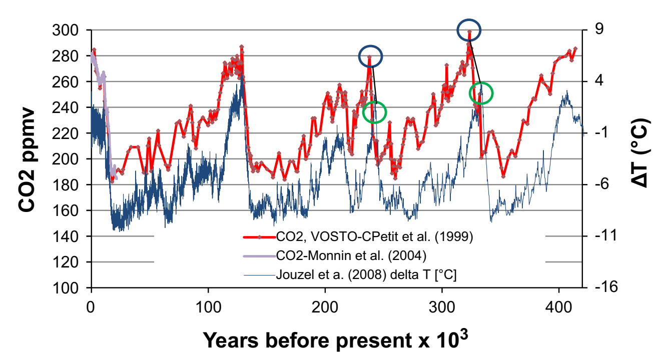

Fig. 6. Temperature difference in Antarctica compared to various CO_2 concentrations Circled points indicate CO_2-concentration increase following the temperature increase by natural causes.

cores. It is clear (see circled points) that the temperature increase by natural causes precedes the CO_2-concentration increase.

On a greater time scale, stomata in leaves of fossil plants can be used as biological sensors of past levels of atmospheric CO_2. Stomata are the pores on the epidermis of leaves that control gas exchange, including uptake of the CO_2 used in photosynthesis. It has been observed that an inverse relationship exists between the number of stomata on the leaves of woody plants and ambient concentrations of CO_2. Retallack [22] has created and validated a record of CO_2 extending back to 300 million years ago. Kurschner [23] presented a comparison of this record to the relative trends in temperature as inferred from the oxygen isotope record of marine fossils [19]. This comparison (Fig. 7) shows a chaotic relation in our view between the two variables. First of all observe that at about 290 million years ago (Ma) the CO_2 levels were about the same as in the present time but the temperature is not. Between 300 and 250 Ma the temperature increases first and then the CO_2 level increase follows. Between 230 and 200 Ma the CO_2 level increases but the temperature remains unchanged. Between 190 and 180 Ma the temperature falls when the CO_2 levels increase for another 10 million years. At about 110 Ma the CO_2 level increases first but the temperature takes more than 5–10 million years to follow the CO_2 increase. At about 35 Ma the temperature starts again to increase but the CO_2 level responds after about 5 million years and continuous to increase 5 million years after the temperature decreases. The above-mentioned behavior can in no way show, or even indicate, that CO_2 levels affect the temperature. As Kurschner [23] states, "data with better temporal resolution are necessary to refine the present picture … it will need much more work to see whether it contains enough clues to establish the exact temporal and causal relationship between CO_2 and climate on a timescale of several million years." Although she argues that "concentrations of CO_2 will probably turn out to have been the main general determinant of temperature and climate during the past half-a-billion years of Earth's history", this is not scientifically established in her analysis, with her finally admitting that "but it is likely that plenty of other factors came into play at different times and to different extents in the past. Changes in the configuration of continents, topography (as in mountain building) and ocean circulation, or in Earth's orbit and the angle of its axis, as well as in solar brightness, can clearly all have a profound influence on climate."

Next by checking how CO_2-concentration has fluctuated over a larger time scale, throughout the Phanerozoic eon, one can definitely draw further conclusions about the former's correlation with the temperature. Palaeo-climatologists calculated palaeolevels of atmospheric CO_2 using the GEOCARB III model [24]. GEOCARB III models the carbon cycle on long time-scales (million years resolution) considering a variety of factors that are thought to affect the CO_2 levels. The results are in general agreement with independent values calculated from the abundance of terrigenous sediments expressed as a mean value in 10 million year time-steps [25]. As shown in Fig. 8A, CO_2 levels were very high, about 20–26 times higher than at present, during the early Palaeozoic—about 550 Ma. Then a large drop occurred during the Devonian (417–354 Ma) and Carboniferous (354–290 Ma), followed by a considerable increase during the early Mesozoic (248–170 Ma). Finally, a gradual decrease occurred during the late Mesozoic (170–65 Ma) and the Cainozoic (65 Ma to present). Also the blue line presents temperature deviations relative to today, adjusted accordingly for pH effects [25]. Fig. 8B presents the intervals of glacial (dark color) and cool climates (light blue). As it is observed from 530 to 480 Ma the CO_2-concentration dropped, followed by a temperature decline between 520 and 450 Ma. Then the temperature increased first from 450 to about 380 Ma, followed by a decline in the CO_2-concentration at first and then an increase. From 380 to about 300 Ma both of them decline. This is also followed by a temperature increase followed by the increase of CO_2-concentration. The logical conclusion drawn from Fig. 8B is that the Earth's temperature fluctuates continuously and CO_2 is not proven to be a major driving factor.

At this point a natural question to ask is about the physical relation between the CO_2 levels and temperature. It is well known that CO_2 dissolves in seawater. When the Earth's temperature decreases the CO_2-concentration in the atmosphere decreases too

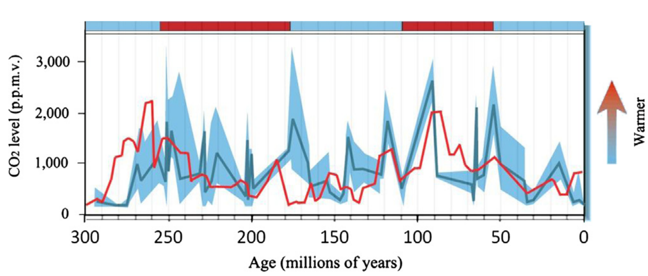

Fig. 7. Levels of CO_2 in the atmosphere (blue line) and temperature trends over the past 300 million years. The CO_2 curve is the mean, with the 'envelope' showing the standard deviation, and is based on Retallack's [22] stomatal-index analysis. Relative trends in temperature are inferred from the oxygen isotope record of marine fossils [19]. Horizontal bars at the top indicate periods of predominantly cool (blue) and warm (red) modes of the Earth's climate (redrawn from [23]). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

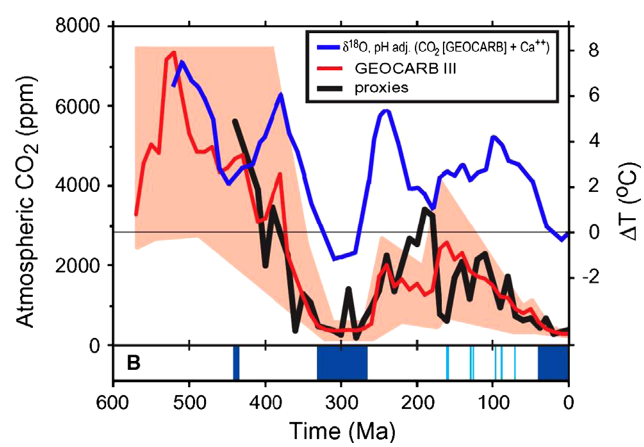

Fig. 8. A. Comparison of model predictions (GEOCARB III; [24]) and proxy reconstructions of CO_2 in 10 million years time-steps. Shaded area represents the range of error for model predictions. Blue line presents temperature deviations relative to today calculated by Shaviv and Veizer [26] from "10/50" $\delta 18O$ data, adjusted for pH effects due to changes in seawater Ca^{++} concentration and CO_2 based on GEOCARB III. B. Intervals of glacial (dark blue) or cool climates (light blue). (Modified from [25]). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

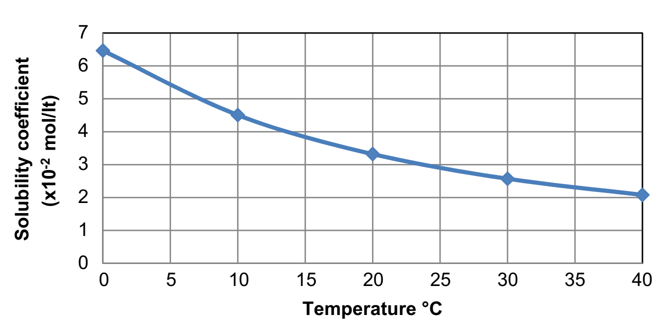

Fig. 9. Solubility coefficient variation of CO_2 in seawater, in equilibrium with the pure gas at a pressure of 1 atm, with regard to temperature.

because the solubility of CO_2 in the seawater increases. This physical phenomenon is very well-established as shown in Fig. 9. For example if seawater of salinity 35 is cooled from 20 °C to 10 °C it will absorb about 35.7% more CO_2 (aq). The solubility coefficient is the concentration of the dissolved gas (CO_2 (aq)), in moles per litre of seawater of a salinity of 35 (Weiss, 1974 in [27]).

2.3. Estimates for the increase in global temperature

A lot of individual but prominent scientists examined the matter from different angles. Archibald [28] presents an interesting comparison of estimates of the effect that CO_2 would have if its concentration in the atmosphere doubles to 600 ppmv, and concludes that the models of the IPCC apply an enormous amount of compounding water vapor feedback and, at their worst, the IPCC models take 1 K of heating and turn it into 6.4 K (see Fig. 10). Idso derived an estimate of climate sensitivity from nature observations. Kininmonth estimates a 0.6 K and this is based on water vapor amplification but also includes the strong damping effect of surface evaporation. Lindzen's estimation is based on water vapor and negative cloud feedback. Spencer examined the data from the Aqua satellite and performed simple model analysis. Finally, the Stefan–Boltzmann figure of 1 K is based on the Stefan–Boltzmann equation without the application of feedbacks and as Archibald comments everybody agrees with this figure when no feedbacks are involved.

2.4. Physical observation

Physical observations and measured data are of paramount importance in estimating the global warming produced by the rising levels of greenhouse gases. Idso [29] presented a comparison for the CO_2 greenhouse effect on Mars, Earth and Venus by plotting the CO_2 warming vs. the CO_2 atmospheric partial pressure on a log-log scale (see Fig. 11). He concludes that considering the consistency of all empirical data, atmospheric CO_2 fluctuations influence surface air temperature largely, independently of atmospheric moisture conditions, because water vapor quantities are practically non-existent on Mars, “medium” on Earth and large on Venus (in an absolute sense). Hence, the long-espoused claim of a many-fold amplification of direct CO_2 effects by a positive water vapor feedback mechanism would appear to be rebuffed by the analysis. As a result, Idso's final conclusion is that the scientific consensus on the strength of the CO_2 greenhouse effect, as expressed in past reports of the U.S. National Research Council, is likely to be in error by nearly a full order of magnitude. Based on the comparative planetary climatology relationship of Fig. 11, a 300–600 ppmv doubling of earth's atmospheric CO_2 concentration should only warm the planet by about 0.4 K.

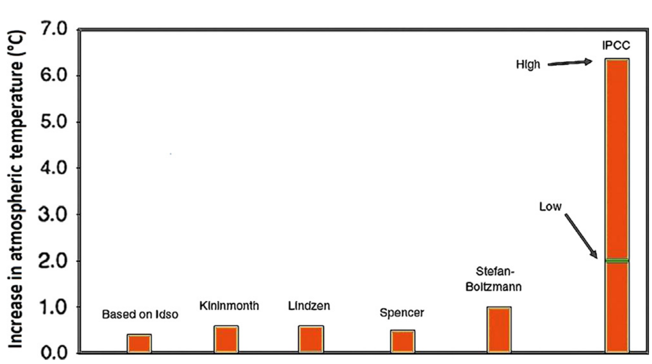

Fig. 10. Archibald's [28] comparison of estimates for doubling the atmospheric CO_2 from its pre-industrial level.

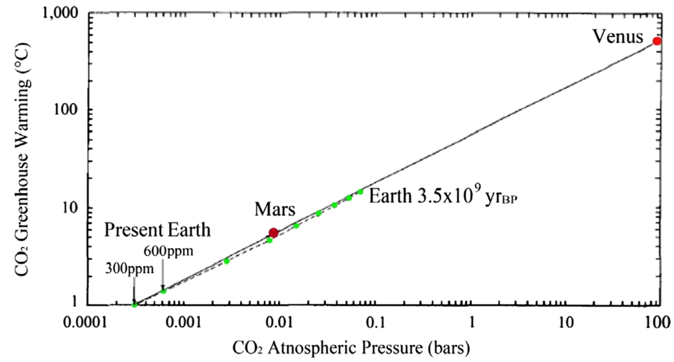

Fig. 11. Comparative planetary climate relationship for Mars, Earth and Venus based on the greenhouse warming of Mars and Venus, which are produced by their atmospheric partial pressures of CO_2 (solid line). Also shown is the almost identical relationship derived from standard considerations related to the Earth's paleoclimatic record and the first early Sun paradox (dashed line) (redrawn from [29]).

2.5. CO_2 concentration and life

On earth we know of only one type of life form that is based on the molecule of carbon. Carbon forms normal chemical bonds with other elements but also forms special type of molecules the so-called organic molecules on which all life is based on. In the human body carbon is the second most abundant element by mass (about 18.5%) after oxygen. So is human life in real danger if atmospheric CO_2 continues to increase the way it already increased during the 20th century? And then, what is the upper limit of CO_2 concentration for absolute danger? In an indoor air test we can find CO_2 levels as high as 600 ppm, which is typical of indoor air and is considered an acceptable and safe level. Note that a 100% CO_2 concentration in the atmosphere corresponds to 1,000,000 ppm, and hence 1% concentration corresponds to 10,000 ppm of CO_2. At 10,000 ppm concentration of CO_2 and under continuous exposure at that level, such as in an auditorium filled with people and poor fresh air ventilation, some individuals are likely to feel drowsy. Toxic levels of CO_2 are reached at levels above 5% [30]. So, it must be clear that at present and near future levels CO_2 does not seem to pose direct danger to human life.

But what about CO_2's usefulness in life? The IPCC [31] mentions that increased CO_2 concentrations can fertilize plants by stimulating photosynthesis, which (as various models suggest) has contributed to increased vegetation cover and leaf area over the 20th century. Increases in the Normalized Difference Vegetation Index (a remote sensing product indicative of leaf area, biomass and potential photosynthesis) have been observed, although other causes, besides the increased CO_2, including climate change itself are also likely to have contributed. Increased vegetative cover and leaf area would decrease surface albedo, which would act to oppose the increase in albedo due to deforestation. The RF due to this process has not been evaluated and there is a very low scientific understanding of these effects.

The full extent of the beneficial effect that CO_2 has on plant life can be found in a website maintained by CO_2 Science [32], where an expanding archive of the results of peer-reviewed scientific studies that report the growth responses of plants to atmospheric CO_2 enrichment can be found. Results from thousands of scientific articles are tabulated according to two types of growth response: dry weight and photosynthesis. Table 1 indicates the mean percentage increase in yield for some important species, for a 300 ppm increase in atmospheric CO_2 concentration.

Moreover, in [33] 55 ways are outlined in which the modern rise in atmospheric CO_2 is benefiting the earth's biosphere, as reported in the peer-reviewed scientific literature. The general conclusion is that rising atmospheric CO_2 concentrations lead to

more numerous and more robust plants, which yearly remove ever-greater quantities of CO_2-derived carbon from the atmosphere, storing it initially in their own tissues, eventually in the soil, and ultimately in the depths of the sea.

3. Earth-orbit climate effects

Astronomers have linked the earth climate to various changes related with the earth orbit around the sun and the amount of energy the earth receives. These orbital processes are thought to be the most significant drivers of ice ages according to the theory of Milankovitch, and such changes are [34] (a) the shape of the orbit (eccentricity) of the earth around the sun, (b) the angle of the earth's axis with respect to its orbital plane (axial obliquity), and (c) the change in the direction of the earth's axis of rotation (precession).

Table 1
Plant dry weight (biomass) responses to atmospheric CO_2 enrichment for 300 ppm increase in atmospheric CO_2 concentration [32].

Cereals		**Vegetables**	
Barley	40%	Cabbages	29%
Rice	36%	Tomatoes	32%
Wheat	33%	Cucumbers	45%
Legumes		**Other**	
Beans	64%	Coffee	175%
Peas	33%	Olive trees	36%
Soybeans	46%	Citrus	30–60%
Roots and tubers			
Carrots	78%		
Potatoes	30%		

The Milankovitch cycles were recently observed and confirmed by the European Project for Ice Coring in Antarctica (EPICA) [35]. EPICA is a multinational European project for deep ice core drilling. Its main objective is to obtain full documentation of the climatic and atmospheric record archived in Antarctic ice by drilling and analyzing ice cores and comparing these with their Greenland counterparts. Jouzel and collaborators [36] mention that the EPICA has provided two deep ice cores in East Antarctica, one at Dome C (EDC) and one in the Dronning Maud Land area (EDML). A high-resolution deuterium profile is available along the entire Dome C ice core, extending the climate record back to marine isotope stage 20.2, i.e. at about 800,000 years ago. Focusing on the EDC ice core Jouzel and collaborators mention that their analysis shows no indication that greenhouse gases have played a key role. The obliquity component of the radiative forcing calculated – accounting for both CO_2 and CH_4 changes – has a small amplitude over the past 650,000 years (~0.5 W m^{-2}, see Fig.12) but it also seems to lag Antarctic and tropical temperature changes. Nor can this in-phase temperature behavior be explained by local insolation, given that this parameter is in anti-phase between low and high latitudes. Rather than assuming that this is caused by greenhouse coupling, they suggest that it results from a transfer of the high-latitude obliquity signal to the tropics. The amplitude of the radiative greenhouse forcing, however, is very important in the

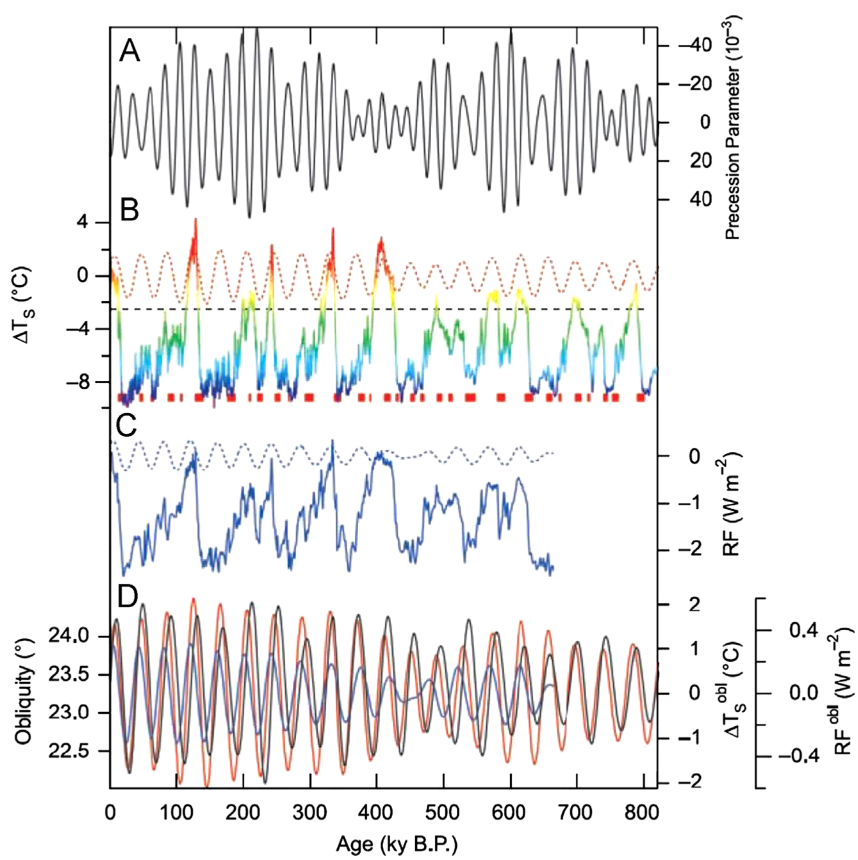

Fig. 12. (A) Precession parameter displayed on an inversed vertical axis (black line). (B) EDC temperature (solid line, rainbow colors from blue – cold temperatures- to red – warm temperatures) and its obliquity component extracted using a Gaussian filter within the frequency range 0.043 ± 0.015 ky^{-1} (dashed red line, also displayed in (D) as a solid red line on a different scaling). Red rectangles indicate periods during which obliquity is increasing and precession parameter is decreasing. (C) Combined top-of-atmosphere radiative forcing due to CO_2 and CH_4 (solid blue) and its obliquity component (dashed blue, also displayed in (D) as a solid blue line on a different scaling). (D) Obliquity (solid black line), obliquity component of EDC temperature (red line), and obliquity component of the top-of-atmosphere radiative forcing due to CO_2 and CH_4 (blue). Insolations were calculated using the Analyseries software [36]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

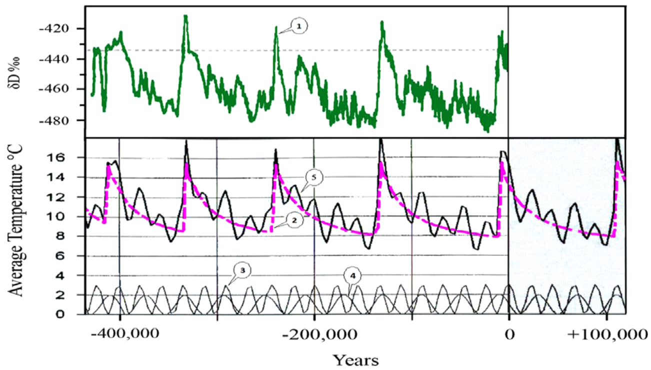

Fig. 13. Resulting temperature deviations (5) with respect to time presenting the combined effect of the attraction of the earth by the moon and the sun (2) and the main harmonic components of the Milankovitch cycles (3)–(4), compared to the Vostok isotope temperature measurements (1) (redrawn from [14]).

100,000-year band (~2.5 W m^{-2}, comparable to the additional greenhouse forcing due to anthropogenic activities). This fact actually points to a strong carbon-cycle feedback involved in the magnitude and possibly duration of ice ages and to a global character of the Antarctic temperature record. The conclusion is that the interplay between obliquity and precession accounts for the variable intensity of interglacial periods in ice core records.

As Sorokhtin and collaborators mention [14] the attraction of the earth by the moon and the sun plays a leading role in the reduction of the precession angle. Precession is caused by the deviation of the earth's mass distribution from the spherical symmetry and is mainly due to the non-uniformity of the earth's crust in its continental and oceanic regions and also in the possible heterogeneity in the mantle density. In their work to estimate the climatic temperature deviations due to the precession angle effect and other Milankovitch cycles, concerning large time-scales, they present a best fit of theoretical to experimental data and project the graph to predict the future climate. In Fig. 13 it is observed that in the past there were slow periods of climatic cooling of about 8–10 °C which lasted approximately 100,000–120,000 years. After the formation of thick ice covers, a rapid warming – by the same 8–10 °C – occurred degrading the glaciers completely in a few thousand years. The change of the earth climate can be explained by the sun radiation and the change in the rotation and orbit of the earth alone. As they suggest CO_2 and other cases have no real role in the climate change. Another important observation is that the temperature a few thousand years ago was higher than the present by roughly 1 K. Their forecast is that in the not so distant future we should expect a significant cooling.

4. The solar activity

A most interesting observation is the sunspot activity, which is related to the amount of radiation that is sent in the cosmic space and reaching the earth. Sunspots are dark, usually circular, features on the solar surface and can be as large as 50,000 km in diameter. They form where denser bundles of magnetic field lines from the solar interior break through the surface and are cooler and darker regions than their surroundings. Solar activity and sunspots change from a minimum to a maximum and back to a minimum in a sunspot cycle. The average period of the sunspot cycle is about 11 years, during which the activity varies from a solar minimum at the beginning of a sunspot cycle to a solar maximum about 5 years later. The maximum number of sunspots varies to approximately 250 of individual sunspots and clusters of sunspots. At the end of a sunspot cycle, the magnetic field quickly reverses its polarity. A change of polarity from one orientation to the other (north to south) and back again covers two successive sunspot cycles and is therefore about 22 years. The sunspot cycle activity has been recorded since 1749 [37].

As the climate on earth depends on the solar activity the observation and measurements of solar radiation and associated sunspot activity is of great importance.

4.1. Solar cycle predictions

In 2001 Badalyan and collaborators [38] predicted from the coronal emission line intensities (the so-called coronal green line (CGL) brightness) of the second half of 1999 a low cycle 24 with the maximal Wolf-number not exceeding 50 (similar to cycles 5–6) and the epoch of maximum at 2010–2011 (see Fig. 14). The Wolf-number is also known as the International sunspot number (ISSN) and their prediction is based on the observation that cyclic variations in the Wolf-numbers follow the green-line variations with a delay of about 10 years. Thus, as they mention, their results infer that we are on the eve of a deep minimum of solar activity similar to that at the beginning of the 19th century.

Since 2006 Archibald [39] indicated the role of solar cycles in climate and popularized monitoring sunspot cycles as a climate prediction tool. By overlapping solar cycle 23 over solar cycle 4, which preceded the Dalton Minimum, showed the similarity between the cycles. Therefore he concluded that July 2009 would be the month of minimum for a thirteen year long solar cycle 23. He suggests that solar cycles 24 and 25 would have amplitudes of approximately 40 SSN and a repeat of the experience of the Dalton Minimum will occur (see also [28]).

A forecast of a team led by Mausumi Dikpata of NCAR [40] has predicted that cycle 24, would peak in 2011 or 2012, and would be intense. The prediction was based on the observed behaviour of the conveyor belt. From May 2006 NASA solar physicist David Hathaway predicted also that solar cycle 25, peaking around the year 2022, could be one of the weakest in centuries (see Fig. 15). This prediction as also based on the observation that the sun's great conveyor belt has slowed to a record-low crawl. The great conveyor belt is a massive circulating current of hot plasma within the sun. It has two branches, north and south, each taking about 40 years to perform one complete circuit. According to theory, the speed of the belt foretells the intensity of sunspot activity for approximately 20 years in the future. A slow belt indicates lower solar activity and a fast belt a stronger activity.

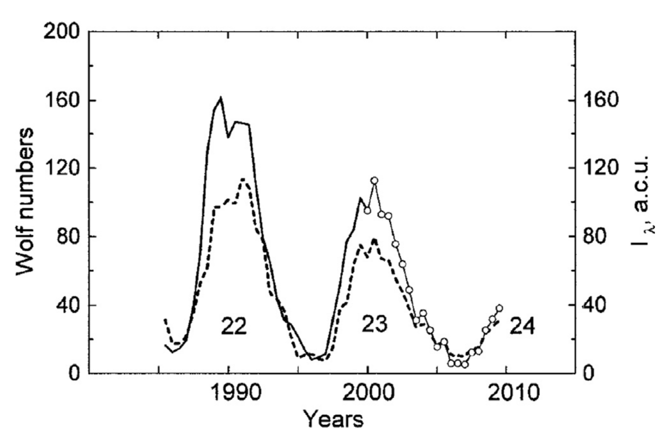

Fig. 14. The part of the cyclic Wolf-number curve (cycles 22–23, solid line) and CGL intensities I_λ (dashed line) shifted forward by 10 years. Open circles indicate the forecast of the Wolf- numbers for solar cycles 23–24 (see [38]). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

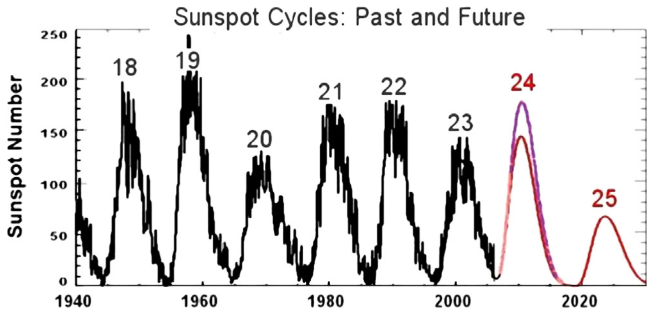

Fig. 15. In red, David Hathaway's predictions for solar cycles 24–25 and, in pink, Mausumi Dikpati's prediction for cycle 24 [4 0 7]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

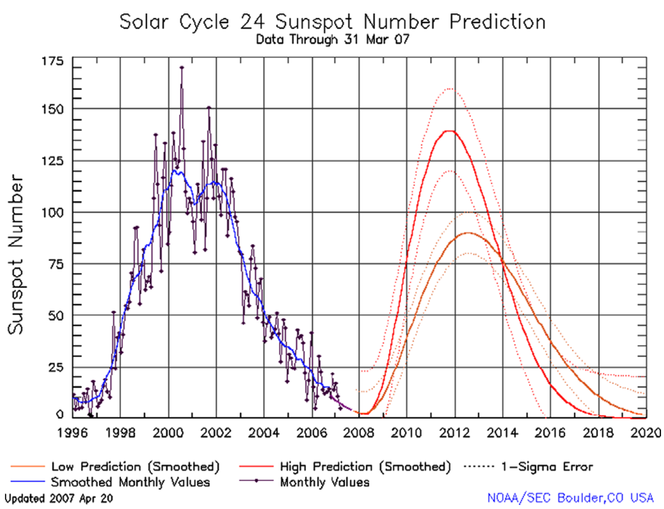

Fig. 16. 2007 Prediction of official solar cycle 24 prediction panel [41].

In October 2006 an Official Solar Cycle 24 Prediction Panel was assembled by NOAA, NASA, ISES and other US and International representatives. The panel met to begin deliberations towards achieving a consensus prediction for the maximum amplitude and timing of solar cycle 24. The panel consisted of voting members and issued a preliminary prediction in the spring of 2007 and also updates in later stages [41]. There were more than 30 wide ranging predictions, both published and submitted directly to the panel, which were considered. In March 2007 the deliberations of the panel supported two possible peak amplitudes for the smoothed ISSN, 140 ± 20 and 90 ± 10. For the large cycle case (ISSN = 140) the panel agreed that solar maximum would occur near October 2011 and for the small cycle (ISSN = 90) the prediction was for August 2012 (see Fig. 16).

The most recent NASA prediction of solar cycle 24, after three years into cycle 24, gives a smoothed sunspot number maximum of about 60 in the spring of 2013. The current predicted size makes this the smallest sunspot cycle in about 100 years [42].

Now after the passage of time we may check how well we understand the sun and its activity by observing its performance for the past years. The very good similarity of sunspot numbers of cycles 1–5 to the recent cycles 20–24 (see Fig. 17), show the presence of a 200-year cycle but no one can still be sure that this is not a coincidence. It is obvious that the sun *is not well-understood* and also that there are large and small sun cycles for which we have not yet a complete set of scientific data to compare.

4.2. Effect of the planetary system on solar activity

It is interesting, we believe, to study the effect that the planetary system may have on the solar activity. As the mass of the sun accounts for the 99.86% of the total mass of the solar system (indicatively Jupiter, the biggest planet, has a mass of less than 1/1000 times that of the sun), it is very natural to assume that the center of mass (CM) of the solar system would be located at the center of the sun [43]. In fact, the center of the sun moves about the CM of the solar system in a series of complex spirals with the distance between the two varying from 0.01 to 2.19 solar radii [44]. This motion is the result of the gravitational forces of the Jovian planets tugging on the sun.

Jose [44] calculated the motion of the sun about the CM of the solar system and showed that the time rate-of-change of the sun's angular momentum about the instantaneous center of curvature varies in a quasi-sinusoidal manner similar to the variation seen in the solar sunspot number. In fact the temporal agreement between

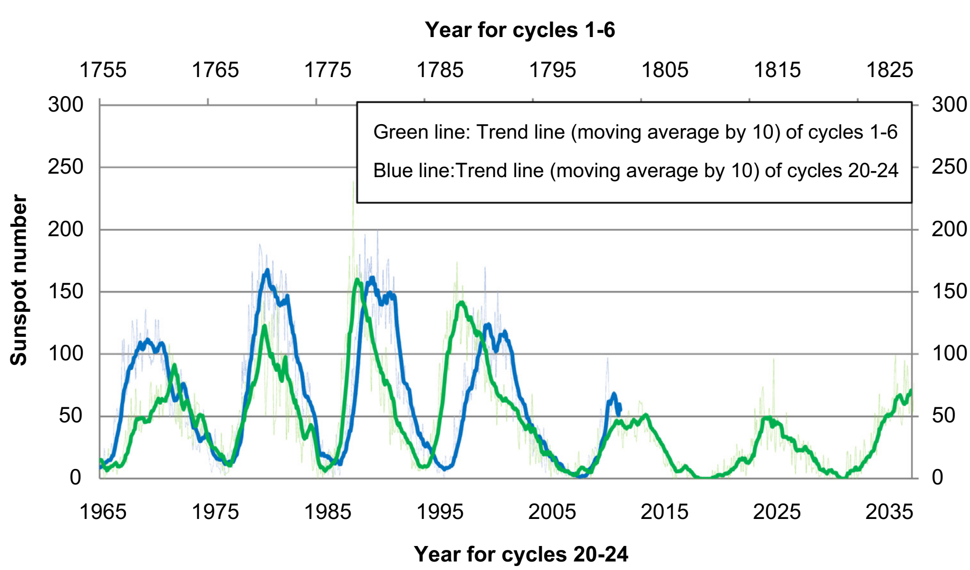

Fig. 17. Green line showing cycles 1–6 lasting for about 70 years (1755–1825) compared to cycles 20–24 for the years 1965 till today [37], showing good similarity and suggesting that cycle 24 and 25 will cause cooling of global temperature. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

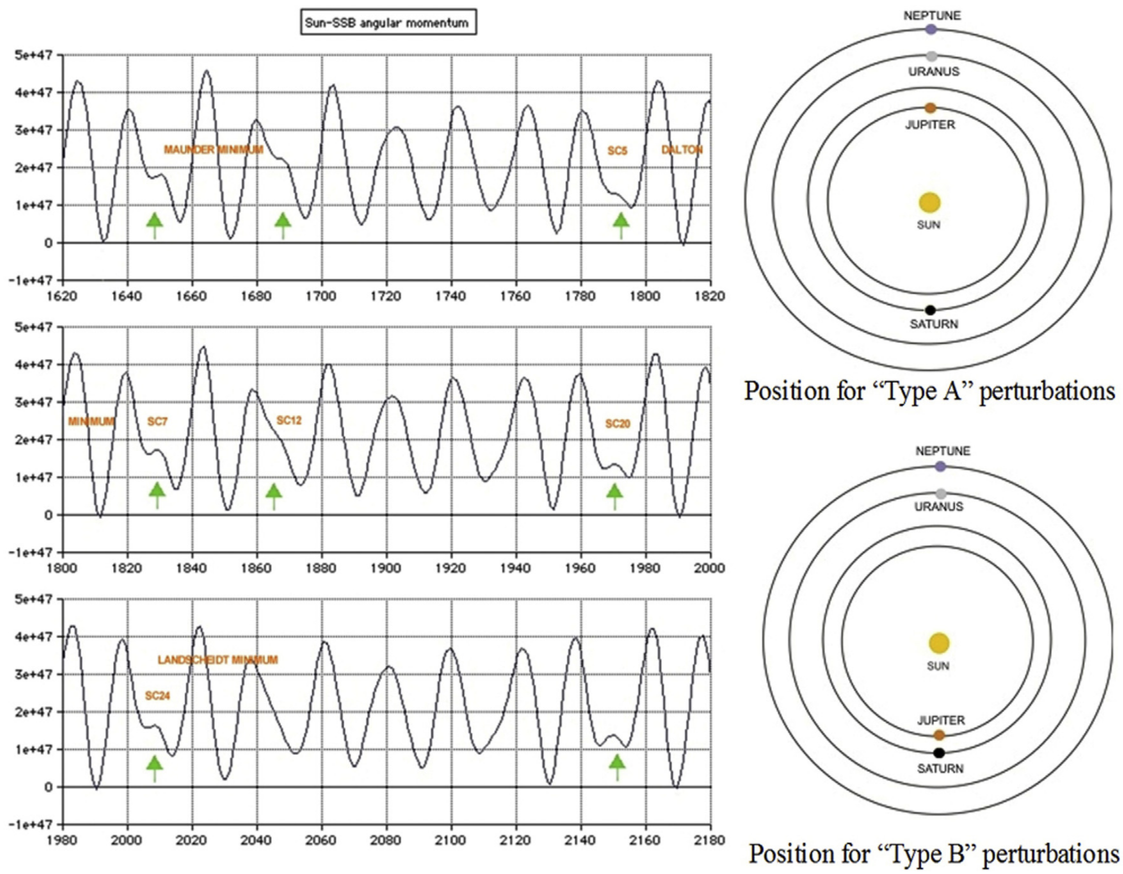

Fig. 18. Detailed solar angular momentum (AM) graphs showing perturbations at the green arrows. The AM perturbations are the result of the extra AM from the Uranus/Neptune conjunction. The timing in relation to the Jupiter/Saturn opposition provides the different perturbation shapes that can be measured via the relevant planet angles and categorized into two groups. Perturbations occurring on the down slope "Type A" and those on the up slope "Type B" (down slope = right hand side of peak)-redrawn from [45].

variations in the rate-of-change of angular momentum and the solar sunspot number were so good that it strongly hinted that there was a connection between the induced forces acting on the sun exerted by the motions of the planets and sunspot activity

Sharp [45] studied the gravitational effects of Jupiter, Saturn, Uranus and Neptune using detailed angular momentum (AM) graphs. In a general sense, the angular momentum (L) of a body with respect to some point of origin is the vector product of its linear momentum (P), which itself is the product of the mass (m) and velocity (v) of an object, and its distance from the origin (r): $P = m \times v$ and $L = m \times v \times r$. The AM perturbations (see Fig. 18) were measured and quantified allowing analysis of past solar cycle modulations along with the 11,500 year solar proxy records (14C and 10Be). It was found that the AM perturbation and modulation is a direct product of the outer gas giants (Uranus and Neptune). This information gives the opportunity to predict future grand minima along with normal solar cycle strength with some confidence. A proposed mechanical link between solar activity and planetary influence via a discrepancy found in solar/planet AM along with current AM perturbations, indicate solar cycles 24–25 will be heavily reduced in sunspot activity resembling a similar pattern to solar cycles 5–6 during the Dalton Minimum (1790–1830).

4.3. Total solar irradiance

It should be, also, of great importance to try and understand how the variation of the total amount of radiation reaching the top of the earth's atmosphere, called total solar irradiance (TSI), affects the climate of the earth. Fig. 19 shows the possible relation

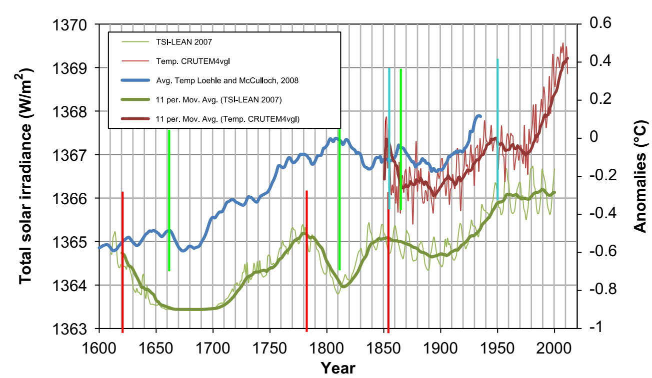

Fig. 19. Comparison between temperature anomalies from 1600 to present [46,47] and the sun spectral irradiance (TSI) [48].

between the temperature anomalies from 1600 to present to the sun spectral irradiance. This specific time-span was chosen because only since then there are fairly accurate data. It must be undoubtedly expected that an increase in the sun irradiance will have as an effect the increase of the global temperature after a certain time-lack. Considering that a non-decreasing amount of irradiance will increase the global temperature further, the only possible time-span that will allow one to estimate the time-lack is when there is a decrease in the irradiance. Such a case can be observed in the years 1620, 1780 and 1850 (although the decrease is not significant). It can be seen that the temperature-decrease response to these decreases occurred at about years 1660, 1810

and 1865 (but also in 1850 and 1945, for the instrument-read data, after the year 1850). Therefore, the 'safe' conclusion is that it is very hard to estimate any time-lacks between TSI and temperature. In any case a 400-year span is hardly sufficient to draw solid conclusions about how the sun affects the global climate. At present (solar cycle 24) TSI is in the verge of a significant decrease, and hopefully this will help in extracting useful information about the relation between temperature and TSI.

4.4. Observing the sun

To study the sun activities for which there is low scientific understanding the Russian-Ukrainian project "Astrometria" was set to measure the temporary variations of the shape and diameter of the sun and the total solar irradiance. The head of the Astrometria project Dr. H. Abdussamatov mentions that the absolute value of TSI began to drop after the 1990s. However, due to the oceans' great thermal inertia earth reacts to the two-century-long changes in TSI with a time-lag of 17 ± 5 years and a minimum will be reached by approximately year 2041 ± 11. Currently observed falling TSI cannot yet exert significant influence. As he mentions it is expected that after cooling of the upper ocean in 5–8 years mankind will feel a very slow global cooling intensified after decades [49]. If so, temperature will be down up to so-called Maunders minimum and will stay at this level for about 45–65 years. After a period of intense cold the next cycle of global warming will begin only at the beginning of the 22nd century and temperature on the planet will start rising gradually. A preliminary scenario of falling average global temperature of the ocean surface in the 21st century and the beginning of the next two-century-long cycle of global climate warming at the beginning of the 22nd century are shown in Figs. 20 and 21.

Consequently, the amount of solar energy supplied to the Earth is directly linked to the value of solar radius, i.e. to the radiating area of our star. Cyclic variations of the TSI occur due to the oscillations of solar radius with amplitude up to 130 km within a "short" 11-year cycle and up to 300 km within a "grand" 2-century cycle.

4.5. Cosmic rays

As with what mechanisms (besides the direct) the sun affects the climate of the earth some theories were put forward. During the 1990s Svensmark and Friis-Christensen presented a new astronomical cause for climate change, that of the cosmic ray hypothesis. Cosmic radiation comprises mainly protons 92%, and alpha particles 6%, with very high energy. When the ray particles reach the atmosphere, they cause ionization in its upper layers and many of the particles are absorbed or lose their energy colliding with other particles in the atmosphere. The earth is shielded from the cosmic rays because the rays are deflected by the earth magnetic field. Also since the solar wind expands the magnetic field of the sun more of these rays are reflected away of the earth when the solar wind is stronger. According to the cosmic ray hypothesis, periods with low solar activity allow more cosmic radiation to reach the earth. The theory suggests that ions and radicals produced in the atmosphere by cosmic rays influence aerosol production and thereby cloud properties. More cosmic rays in the atmosphere will produce more low clouds, and finally a lower global mean temperature will result because of this.

In examining the above-mentioned hypothesis the Danish National Space Center [50], identified five external forcing parameters that are modulated by solar variability and have the potential to influence the earth's lower atmosphere below 50 km. These factors are: (a) the Total Solar Irradiance (TSI), (b) the Ultra-Violet (UV) component of solar radiation, (c) the direct input from the Solar Wind (SW), (d) the total Hemispheric Power Input (HPI) reflecting properties of precipitating particles within the magnetosphere, and (e) the Galactic Cosmic Rays (GCR). Their conclusion is that UV and GCR present a striking correlation with the global coverage of low clouds, over nearly two and a half solar cycles as shown in Fig. 22.

Currently, the National Space Institute of Denmark (DNSI) [51] has been investigating the above hypothesis. The reported variation of cloud cover was approximately 2% over the course of a sunspot cycle but this would result in a comparable global warming to that presently attributed to human activity. DNSI assumes that ions and radicals produced in the atmosphere by cosmic rays could influence aerosol production and since aerosols work as precursors for the formation of cloud droplets, this is an indication that cosmic rays influence cloud formation. DNSI in cooperation with the European Organization for Nuclear Research, CERN and other organizations, created an atmospheric research facility (CLOUD) that consist of a special cloud chamber exposed to pulses of high-energy particles from one of CERN's particle accelerators, were experiments are performed to check and understand the role of cosmic rays in the formation of clouds [52].

5. Conclusions

It is common knowledge that the sun powers the climate of the earth by radiating its energy. But in the recent decades the increase in atmospheric CO_2 concentration has been heavily linked to (and blamed for) the observed increase in global temperature,

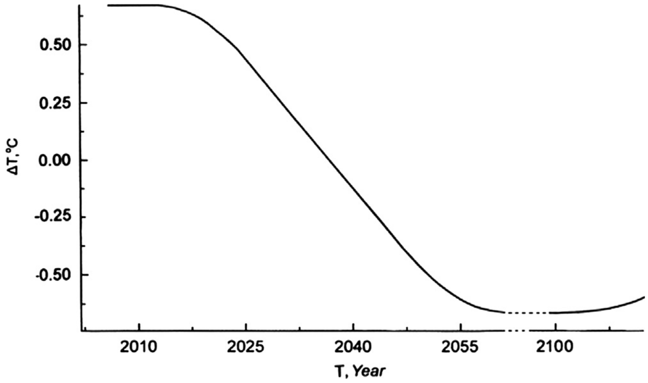

Fig. 20. Scenario of the deep cooling of the climate (redrawn from [49]).

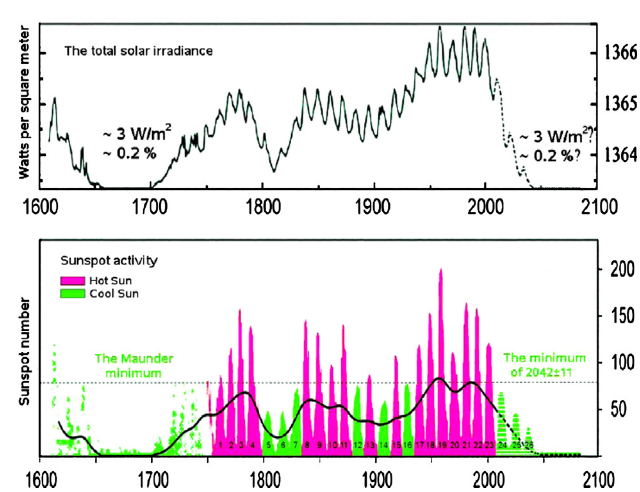

Fig. 21. Total solar irradiance and sunspot activity with prediction for the present aeon (redrawn from [49]).

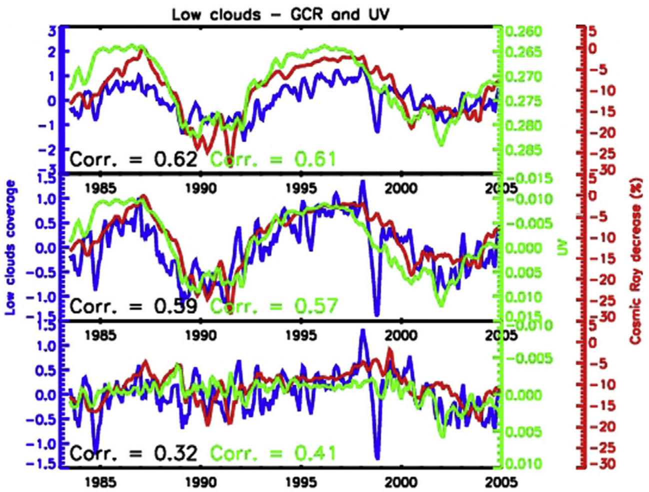

Fig. 22. Correlation between GCR (red) and UV (green) and coverage of low clouds (blue). ISCCP data for coverage of low altitude clouds after adjustment for their offset when compared with the independent data set of low cloud. From top: annual cycle removed, trend and internal modes removed, solar cycle removed (modified from [50]). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

despite the fact that CO_2's presence in the atmosphere is very limited into minor amounts. The influence of many other factors that could be of high importance in affecting the global temperature has not so far been well studied and the related level of scientific understanding remains low. Such major factors are solar irradiance and water vapor, with about 30 more parameters being contained in global climate system models. The extraction of conclusions from such models derived without any sound theoretical background becomes merely a form of data curve fitting by "manipulating" the parameters and have no rigorous scientific value. Predictions of climate models compared to the actual satellite observations for global temperature show substantial deviation, pointing to the limitations of the existing models. Additionally, observing the global temperature and the CO_2 atmospheric concentration though the geological aeons implies no obvious correlation.

Physical observations on other planets confirm that independently of atmospheric moisture conditions, the atmospheric CO_2 partial pressure influences in a specific log-log relation the surface air temperature.

A lot of individual but prominent scientists examined the matter from different angles and arrived at the conclusion that at the most, doubling the atmospheric CO_2 from its pre-industrial level, will cause an increase in atmospheric temperature by 1 K as opposed to IPCC's mean estimate of 3 K.

All living organisms are based on carbon and carbon organic chemistry. Carbon at present concentrations, but even at overestimated near-future concentrations – due to anthropogenic emissions – is still not in the range of a pollutant. On the contrary plants will benefit greatly because of this increase.

Scientifically it was shown that the earth climate is affected by various cyclic changes related with the earth orbit around the sun and the amount of energy the earth receives. The Milankovitch cycles, named after the man who studied them, were recently observed and confirmed by the EPICA. These cycles suggest that in the not so distant future we should expect a significant cooling.

Turning our interest on the sun, we find that the scientific understanding of its behavior is rudimental. For instance NASA, NOAA and other organizations operated in recent years by consensuses and on most occasions went wrong on their predictions. Comparison of solar cycles 1–6 lasting for about 70 years (1755–1825) compared to cycles 20–24 for the years 1965 through today, show good similarity and suggest cyclicity and therefore indicate that cycles 24 and 25 will cause cooling of global temperature. Empirical data show that this cyclicity is caused by the relevant position of the planets. Our recorded data, of about 2 centuries, on solar activity are not yet sufficient to determine its relation to global temperature. To study therefore, the sun activities the project "Astrometria" was set to measure the temporary variations of the shape and diameter of the sun and the total solar irradiance. Solar activity may affect the climate on earth not only directly but indirectly as well. The cosmic ray hypothesis suggests that periods with low solar activity allow more cosmic radiation to reach the earth. Cosmic rays influence aerosol production and thereby cloud formation. More cosmic rays in the atmosphere will produce more low clouds, and finally a lower global mean temperature will result because of this. This theory is now under investigation by DNSI in cooperation with the European Organization for Nuclear Research, CERN and other organizations.

Concluding, all the above show that in the case when there is no sound scientific understanding of physical phenomena, no sound and absolute conclusions should be drawn. We believe that specific care should be taken not only for the sake of science's good name but also for matters that may have political aspects and affect the human societies.

References

[1] Florides G, Christodoulides P. Global warming and carbon dioxide through sciences. Environmental International 2009;35:390–401.

[2] Ciattaglia, L Rafanelli, C Rodriguez, H Araujo, J. Jubany Station, Antarctica. Monthly and annual atmospheric CO_2 record from continuous measurements. Atmospheric CO_2 mixing ratios expressed in ppmv, relative to the NOAA/GMD standards. 2010. Available electronically from: ⟨http://cdiac.ornl.gov/ftp/trends/co2/Jubany_2009_Monthly.txt⟩.

[3] Svensmark H. Evidence of nearby supernovae affecting life on Earth. Danish National Space Center 2012. ⟨http://www.spacecenter.dk/research/sunclimate/Scientific%20work%20and%20publications⟩.

[4] IPCC fourth assessment Report: climate change: synthesis report, 2007, ch2.2, Fig. 2.4.⟨http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains2-2.html⟩.

[5] Florides G, Christodoulides P, Messaritis V. Global warming: CO_2 vs sun. In: Harris Stuart Arthur, editor. Source: global warming, book. Publisher: Sciyo; 2010.

[6] Haigh JD. The sun and the earth's climate,. Living Reviews in Solar Physics 2007;4–2. ⟨http://www.livingreviews.org/lrsp-2007-2⟩.

[7] IPCC fourth assessment report, climate change 2007: working group I: the physical science basis, Ch. 1.5, FAQ 1.3 ⟨http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-1-3.html⟩.

[8] IPCC climate change 2007: working group I: the physical science basis. Observations: surface and atmospheric climate change Ch. 3.4.2- water vapour p 271 ⟨http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter3.pdf⟩.

[9] IPCC third assessment Report—climate change 2001:working group I: the scientific basis. F.3 projections of future changes in temperature. ⟨http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/031.htm⟩.

[10] IPCC fourth assessment Report: climate change 2007. Climate change 2007: synthesis report. 2.3 climate sensitivity and feedbacks. ⟨http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains2-3.html⟩.

[11] IPCC fourth assessment Report: climate change 2007: working group I: the physical science basis. 10.3 projected changes in the physical climate system, Fig. 10.4 ⟨http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure–10–4.html⟩.

[12] IPCC fourth assessment Report: climate change 2007: working group I: the physical science basis. TS.4.1 advances in attribution of changes in global-scale temperature in the instrumental period: atmosphere, ocean and ice ⟨http://www.ipcc.ch/publications_and_data/ar4/wg1/en/tssts-4-1.html⟩.

[13] Committee on the science of climate change—National Research Council, climate change science: an analysis of some key questions. National Academy Press; 2001. ⟨http://www.nap.edu/openbook.php?record_id=10139&page=15⟩.

[14] Sorokhtin OG, Chilingar GV, Khilyuk LF. Global warming and global cooling. evolution of climate on earth, developments in earth & environmental sciences. . Elsevier; 2007.

[15] Spencer R, Global warming slowdown: the view from space 2013; ⟨http://www.drroyspencer.com/2013/04/global-warming-slowdown-the-view-from-space/⟩.

[16] Veizer J. Celestial climate driver: a perspective from four billion years of the carbon cycle. Geoscience Canada 2005;32:1.

[17] IPCC, climate change 2001: the scientific basis: Cambridge University Press., 2001.

[18] Berner U, Streif H. Klimafakten, Der Rückblick - Ein Schlüssel für die Zukunft: Stuttgart: E. Science Publishers; 2000 Schweizerbart'sche Verlagsbuchhandlung.

[19] Veizer J, Godderis Y, Francois M. Nature 2000;408:698–701.
[20] Petit J-R, et al. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Nature 1999;399(6735):429–36, http://dx.doi.org/10.1038/20859. ⟨http://doi.pangaea.de/10.1594/PANGAEA.55501?format=html⟩.
[21] Monnin E, et al. Evidence for substantial accumulation rate variability in Antarctica during the Holocene, through synchronization of CO_2 in the Taylor Dome, Dome C and DML ice cores. Earth and Planetary Science Letters 2004;224(1–2):45–54, http://dx.doi.org/10.1016/j.epsl.2004.05.007. ⟨http://doi.pangaea.de/10.1594/PANGAEA.472488?format=html⟩.
[22] Retallack JA. 300-million-year record of atmospheric carbon dioxide from fossil plant cuticles. Nature 2001;411:287–90.
[23] Kurschner W. Leaf sensor for CO_2 in deep time. Nature 2001;411:247–8.
[24] Berner RA, Kothavala Z. GEOCARB III: a revised model of atmospheric CO_2 over Phanerozoic time. American Journal of Science 2001;301:182–204.
[25] Royer D, Berner R, Montañez I, Tabor N, Beerling D. CO_2 as a primary driver of Phanerozoic climate. GSA Today 2004;14(3):4–10.
[26] Shaviv NJ, Veizer J. Celestial driver of Phanerozoic climate? GSA Today 2003;13(7):4–10.
[27] Skelton P, editor. The cretacious world, 0521538432. The Open University, Cambridge: Cambridge University Press; 2006.
[28] Archibald D. Solar cycle 24. Success Print, ISBN:978-0-646-50269-4, 2008.
[29] Idso S. The CO_2 greenhouse effect on Mars, Earth and Venus. The Science of the Total Environment 1988;77:291–4.
[30] InspectAPedia, toxicity of carbon dioxide gas exposure, CO_2 poisoning symptoms, carbon dioxide exposure limits, and links to toxic gas testing procedures ⟨http://www.inspectapedia.com/hazmat/CO2gashaz.htm⟩.
[31] IPCC fourth assessment Report: climate change 2007. Chapter 2: changes in atmospheric constituents and in radiative forcing, 2007. ⟨http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf⟩.
[32] Center for the study of carbon dioxide and global change. CO_2 science, 2012, ⟨http://www.co2science.org/index.php⟩.
[33] Idso CD, Idso SB. The many benefits of atmospheric CO_2 Enrichment, Science and Public Policy Institute (Vales Lakes Publishing, LLC, Pueblo West, Colorado, USA).
[34] NASA Milankovitch, 2012. ⟨http://earthobservatory.nasa.gov/Features/Milankovitch/⟩.
[35] EPICA European Project for Ice Coring in Antarctica (EPICA), 2012.⟨http://www.esf.org/activities/research-networking-programmes/life-earth-and-environmental-sciences-lesc/completed-esf-research-networking-programmes-in-life-earth-and-environmental-sciences/european-project-for-ice-coring-in-antarctica-epica-page-1.html⟩.
[36] Jouzel, J., et al. Orbital and millennial Antarcticclimate variability over the past 800,000 years. Science, 2007. 317; 5839, 793–797, http://dx.doi.org/10.1126/science.1141038.
[37] Solar Physics Group, NASA's Marshall Space Flight Center. Royal Observatory, Greenwich—USAF/NOAA Sunspot Data. ⟨http://solarscience.msfc.nasa.gov/greenwch/spot_num.txt⟩.
[38] Badalyan OG, Obridko VN, Sýkora J. Brightness of the coronal green line and prediction for activity cycles 23 and 24. Solar hysics 2001;199(2):421–35.
[39] Archibald D. Solar cycles 24 and 25 and predicted climate response. Energy and Environment 2006;17:29–38.
[40] NASA Science, long range solar forecast, ⟨http://science.nasa.gov/science-news/science-at-nasa/2006/10may_longrange/⟩.
[41] NASA Official Solar Cycle 24 Prediction Panel, ⟨http://www.swpc.noaa.gov/SolarCycle/SC24/index.html⟩.
[42] NASA Solar Science, ⟨http://solarscience.msfc.nasa.gov/predict.shtml⟩.
[43] Wilson IRG, Carter BD, Waite IA. Does a spin–orbit coupling between the sun and the jovian planets govern the solar cycle? Astronomical Society of Australia 2008;25:85–93.
[44] Jose PD. Sun's motion and sunspots. Astronomical Journal 1965;70(3):193–200.
[45] Sharp, G. Are Uranus & Neptune responsible for Solar Grand Minima and Solar Cycle Modulation?, e-print arXiv:1005.5303, bibliographic code: 2010arXiv-1005.5303S., 2010, ⟨http://arxiv.org/abs/1005.5303v3⟩.
[46] Loehle C, McCulloch JH. Correction to a 2000-year global temperature reconstruction based on non-treering proxies. Energy & Environment 2008;19(1):93–100.
[47] CRUTEM4vGL. Land air temperature anomalies on a 5° by 5° grid-box basis variance adjusted, Dataset developed in conjunction with Hadley Centre of the UK Met Office, ⟨http://www.cru.uea.ac.uk/cru/data/temperature/#datdow⟩.
[48] Lean J. Evolution of the sun's spectral irradiance since the Maunder minimum. Geophysical Research Letters 2000;27:2425–8.
[49] Abdussamatov H., The sun defines the climate (translated from Russian by Lucy Hancock), Nauka i Zhizn (Science and Life) 2009; N1:34–42. ⟨http://www.gao.spb.ru/english/astrometr/abduss_nkj_2009.pdf⟩.
[50] Marsh N, Svensmark H, Christiansen F, Bondo T. Influence of solar activity—cycles on Earth's Climate Danish National Space Center, June 23, 2006. ⟨http://www.space.dtu.dk/upload/institutter/space/forskning/06_projekter/isac/wp_301_302_401_402.pdf⟩.
[51] DNSI—The National Space Institute in Denmark, 2007, ⟨http://www.space.dtu.dk/English/Research/Research_divisions/Sun_Climate.aspx⟩ Source: Svensmark H., Cosmoclimatology: a new theory emerges, Astronomy & Geophysics 2007; 48(1):1.18–1.24.
[52] CERN—CLOUD outreach, 2010, ⟨http://cloud.web.cern.ch/cloud/Physics/Physics.html⟩.